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Empirical Determination Of Bending Loss In Fibre Optics **Due** To Pneumatic Effect.

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ABSTRACT:

Bending loss is an induced pneumatic effect that inhibits the bandwidth advantage carriage of fibre Optics over other medium for data communication. Information Technology be it audio, image, telegraphy, telephony etcneeds efficient and transparent carrier network system,to enable the output signal be the exact replica of the input signal. Optic fibre has been rated the best medium for signal transmission because of its good characteristic qualities. Despite these high qualities which include:large bandwidth, immunity to electrical andmagnetic interferences, low noise level etc. intrinsic and extrinsic factors have equally mitigated the operational capabilities of optic fibre. The intrinsic factors from molecular displacement of structural composition lead to various types of dispersionwhile the extrinsic factors of temperature and pressureare catalyst in the reduction of power budget and Bit Error Rate (BER).Fibre optics being a fragile material reacts sharplyto pneumatic forces and leads to signal broadening. This effect is called bending loss and this paper examines: causes, consequences and proffers solution to its findings.

I. INTRODUCTION

Fiber Optics has been rated the best media for communication in information dissemination the world over .Suffice to state that this fiber optics despite its various advantages,which includes but not limited to, large bandwidth, and immunity to electrical and magnetic interferences, external electrical noise has no direct effect atits operating frequency,minimal cross talk, lightweight etc. It is important to note that for effective communication the output signal at the destination must be a replica of the input signal at the source. The rating of fiber optics as the best medium for communication has intrinsically not absorbed it from impediments or imperfection. In actual fact the fundamental scattering of absorption process, such as Rayleigh scattering which occurs at molecular level has been the sources of majority of defects in fiber optics. Adequate and proper installation safe guides the fiberoptics to a large extent;however the fundamental issues of intrinsic and extrinsic effects cannot be neglected, such as external forces of temperature and pressure.The later causes stress and strain on the fiber which initiates signal broaden in the fiber optics. They cause various types of distortion in the transmission process such as polarization mode dispersion(PMD),birefringence,group velocity dispersion (GVD),intramural/intermodal dispersion,chromatic dispersion (CD), bending loss etc.It is important to recall that ideally an optic fiber source must be capable of direct modulation of any of the characteristics of a signal, namely frequency, phase or amplitude. A fact that cannot be swept under the carpet is that fiber optics is a very fragile material and as such, very delicate to handle,if the optical alignment is disturbed it encounter's degradation in signal value. Bending loss is a characteristic of molecular displacement in the structure of the fiber composition and this eventually leads to signal broadening bending i.e. signal degradation .The root cause ofbending loss to a greater percentage is pressure.

II. MATERIALS AND METHOD

2.1SPECRUM ANALYSIS OF DEGREADATION IN OPTIC FIBRE DUE TO PNEUMATIC EFFECT

Fibre optics attenuation can be majorly categorized into two namely: Intrinsic and extrinsic factors. The intrinsic factor boarders scattering and absorption processes (leaky mode), while the extrinsic revolves around bending :Large radii of curvature R>1 and micro bending small radii of curvature $R \leq 1$ Mode coupling and radiation **Bending Losses.**

Radioactive losses occur whenever an optical fibre undergoes a bend of finite radius of curvature at this point if not well treated it creates attenuation. Fibre can be subjected to two types of bending (Harus, 1986)

(a) Macroscopic bends and Microscopic bends: These are bends having radii that are large (compared with the fibre diameter, for example such as those that occur when a fibre cable turns a corner) or small radii caused by manufacturer pronenon-uniformities.

(b) Random microscopic bends of the fibre axis that can arise when the fibre are incorporated into cable.

• **Macro chromatic Losses or Simply Chromatic Losses**: For slight bends the excess loss is extremely small and is essentially unobservable. As the radius of curvature decreases, the loss increases exponentially until at a certain critical radius the curvature loss becomes observable. If the bend radius is made a bit smaller once this threshold point has been reached, the losses suddenly become extremely large (Gerd, 2000).

Qualitatively, these curvature loss effects can be explained by examining the modal electric field distribution. It is observed that any bound core mode has an evanescent field tail in the cladding, which decays exponentially as a function of distance from the core. Since this field tail moves along with the field in the core, part of the energy of a propagating mode travels in the fibre cladding. When a fibre is bent, the field tail on the far side of the center of curvature must move faster to keep up with the field in the core, as is shown in Fig 1 (Marcatili,*et al*; 1969)for the lower order fiber mode.

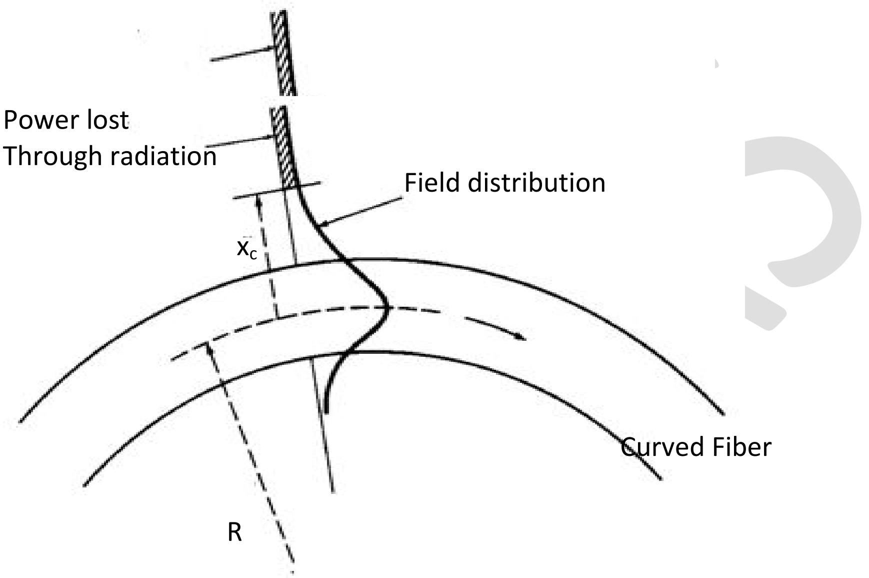

Figure 1 : Sketch of the fundamental mode field in a curved optical waveguide, Bell Sys. Tech. J.

Since this is not possible the optical energy in the field tail beyond x_c radiates away. The amount of optical radiation from a bent fibre depends on the field strength at x_c and on the radius of curvature *R*. since higher order modes are bound less tightly to the fiber core than lower mode, the higher order mode will radiate out of the fiber first. Thus, the total number of modes that can be supported by a curved fiber is less than in a straight fibre. According to Globe (1979), has derived the following expression for the effective number of modes that are guided by curved multimode fiber of radius *α*:

$$N_{eff} = N_{\infty}\left(1 - \frac{\alpha+2}{2\alpha\Delta}\left(\frac{2a}{R} + \left(\frac{3}{2\pi_2 kR}\right)^{2/3}\right)\right) \quad (1.1)$$

Where a defines the graded-index profile, α is the core-cladding index difference, n_2 is the cladding refractive index, k= 2π/λ is the wave propagation constant, and is the total number of modes in a straight fiber.

$$N_{\infty} = \frac{\alpha}{\alpha+2}(n_1 k\alpha)^2 \Delta$$

(1.2)

- **Microbends:** Another form of radiation loss in optical waveguides results from mode coupling caused by random microbends of the optical fibre (Gerd, 2000). Microbends are repetitive small-scale fluctuations in the radius of the fibre axis, as is illustrated in Fig 2. They are caused either by non-uniformities in the manufacturing of the fibre or by non-uniform lateral pressures created during the cabling of the fibre. The later effect is often referred to as *cabling* or *packaging losses*. An increase in attenuation results from micro-

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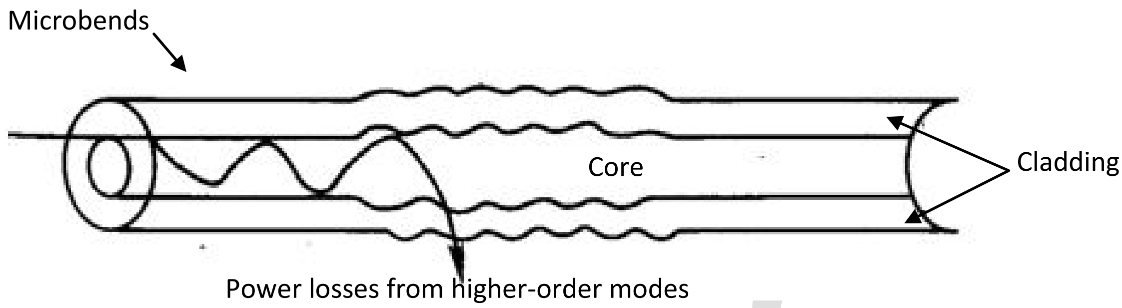
bending because the fibre curvature causes repetitive coupling of energy between the guided modes and the leaky or non-guided modes in the fibre.

Fig 2a



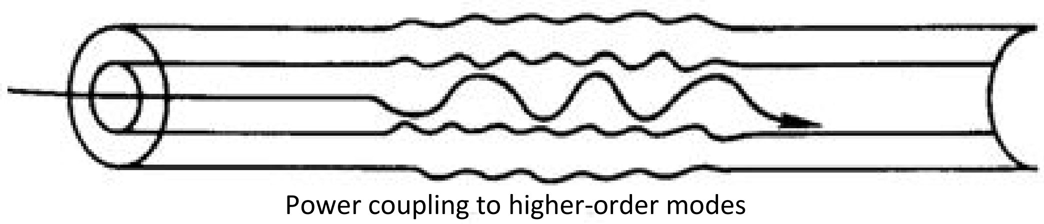


Fig 2b Power coupling to higher-order modes

Fig 2: small-scale fluctuations in the radius of curvature of the fibre axis lead to micro chromatic losses. Microbends can shed higher-order modes andcan cause power from low-order modes to couple to higher-order modes(Gardner, 1978).One method of minimizing micro-chromatic losses is by extruding a compressible jacket over the fibre. When external forces are applied to this configuration, the jacket will be deformed but the fibre will tend to stay relatively straight, as shown in Fig 1.4. For a multimode graded-index fiber having a core radius *a*, outer radius *b* (excluding the jacket), and index difference Δ, the micro bending loss – of a jacket fiber is reduced from that of an unjacketed fiber by a (Gerd, 2000)

$$F(\alpha_M) = \left[1 + \pi\Delta^2 \left(\frac{a}{b}\right)^4 \frac{E_f}{E_j} \right]^{-2} \qquad (1.3)$$

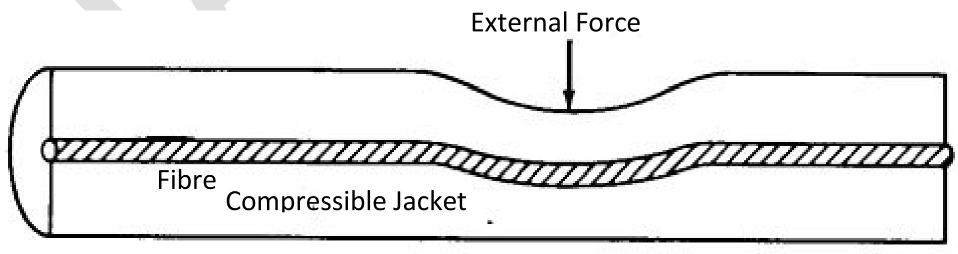


Fig 3: A compressible jacket extended over a fiber reduces microbending resulting from external forces, (Gerd, 2000)

Here $E_j$and$E_f$are the Young's moduli of the jacket and fibre, respectively. The Young's modulus of common jacket materials ranges from 20 to 500Mpa. The young's modulus of fused silica glass is about 65 Gpa. Fig 3 show the feature in a compressible jacketed fibre.

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III. CORE AND CLADDING LOSSES

Upon measuring the propagation losses in an actual fibre, all the dissipative and scattering losses will be manifested simultaneously. Since the core and cladding have different indices of refraction and therefore differ in composition, the core and cladding generally have different attenuation coefficients, denoted by α_1 and α_2 respectively. If the influence of modal coupling is ignored; the loss for a mode of order (v,m) for a step-index waveguide is, (Gerd, 2000)

$$\alpha_{vm} = \alpha_1 \frac{P_{core}}{P} + \alpha_2 \frac{P_{clad}}{P} \qquad (1.5)$$

Where the fractional powers are $\frac{P_{core}}{P_{clad}}$ and $\frac{P_{clad}}{P}$

This could also be written as

$$\alpha_{vm} = \alpha_1 + (\alpha_2 - \alpha_1) \frac{P_{clad}}{P} \quad (1\text{-}4)$$

The total loss of the waveguide can be found by summing over all modes weighted by the fractional power in that mode.

For the case of a graded-index fiber the situation is much more complicated. In this case, both the attenuation coefficients and the modal power tend to be functions of the radial coordinate. At a distance r from the core axis the loss is (Midwinter, 1978).

$$\alpha_r = \alpha 1 + \left(\alpha_2 - \alpha_1\right) \frac{n^2(O) - n^2(r)}{n^2(O) - n_2^2} \qquad (1.5)$$

Where α_1 and α_2 are the axial and cladding attenuation coefficients, respectively. The loss encountered by a given mode is therefore given as, (Marcuse, 1991):

$$\alpha_{gi} = \frac{\int_0^\infty a(r)p(r)rdr}{\int_0^\infty p(r)rdr} \qquad (1.6)$$

Where *p(r)* is the power density of that mode at *r*. It has been observed that the loss increase with increasing mode number (Marcuse, 1991). Once more it is necessary to state that almost all the defects in optic fibre leads to chromatic disperse naturally the transmission of signal in fibre optics boards between the core and cladding at any point of radius.When the phase front associated with the guide sweeps around a bend it must remain plane and perpendicular to the core axis, hence the energy travels slower in the inside of the bend. As the distance from the core increases away from the centerof curvature a point occurs where the phase front is required to travel faster than normal for a wave in the cladding which is supposed to be impossible. So if there is significant portion of evanescent field beyond this point, the portion will simply radiate away robbing the guided mode of energy .The magnitude of bending loss increases dramatically once the radius of curvature is of a fiber optics is reduced below some threshold value which depends on the fiber type .For step index multimode fiberthe threshold value is given by

$$R_t = \frac{3n_1^2\lambda}{4\pi(n_1^2 - n_2^2)^{\frac{3}{2}}}$$

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Where the operating wavelength n_1 and $n_2$are the core and cladding indices respectively.Fibre with large refractive index differences can be extremely resistance to bending loss.

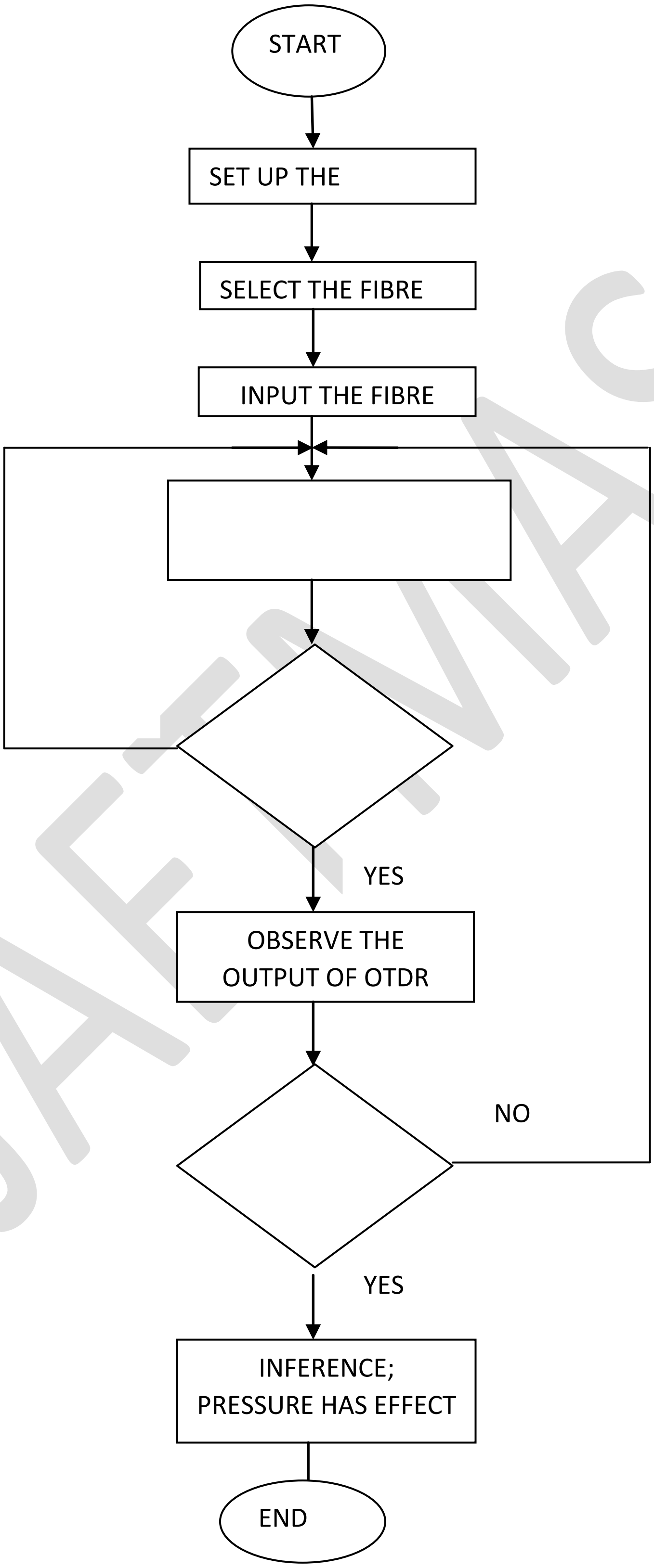

Fig 4 : Flow chart

2.2 Determination of the Effect of Pneumatic Force on Pulse Spreading on Optic Fibre Strand: Crush/Impact Test,

The process ofestablishing. he attenuation factors in optic fiber due to pneumatic forces are operated in the flowchart, fig 4 The situation was viewed practically to enable the threshold value be obtained and adequate precaution be proffered to eliminate pressure effect on installed fiber optics cables. In the light of this fact the cable was subjected under various tensile stress results obtained and analyzed. Cable crush and impact are very important but rarely understood details of optic fibre cables. The IEC794-1-E3/ EIA-RS-455-41/FOTP41 and IEC794-1-E4/ EIA-RS-455-45/FOTP45 details the crush and impact test methods of optic fibre cables to ascertain how well the cable may withstand or recover from a slow crushing or compressive action or repeated impact loads. This test was practically carried out on existing route These problematic routes happen to be in areas, where they were exposed to crush and impact strain from heavy vehicles, so the crush and impact tests were carried out immediately as they contributed to chromatic dispersion in optic fibre.

A related problem has been solved by using a silicon micro machined pressure sensor to obtain the micro-bending induced in an optical fibre(Neguty, 1982). In the present work, instead of the silicon micro-machined pressure sensor, a simple load varying system was adopted. The setup of the work is shown in Fig 5.the applied force came through varying loads and the spreading broadly came as a result of the increased pressure on the fibre.

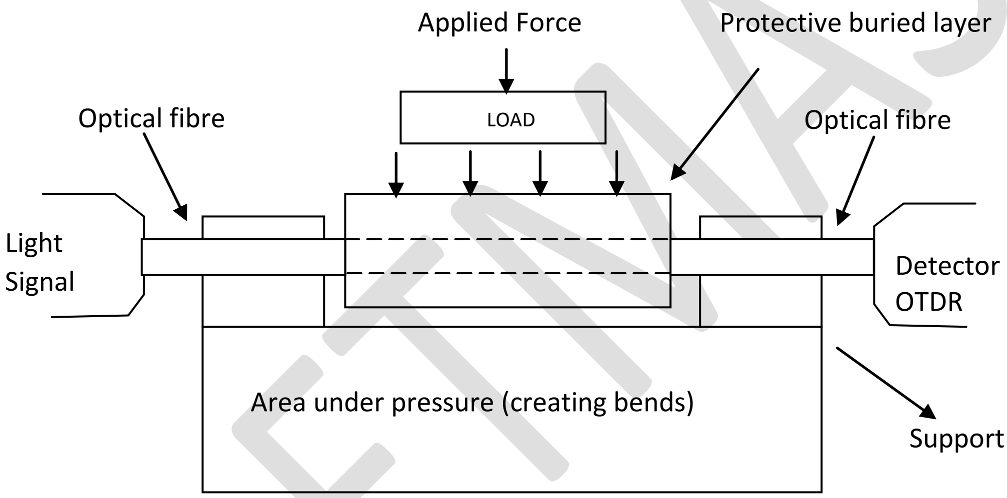

Fig 5: Measurement of Pressure Effect in Optical FibreThe OTDR was used to monitor the signal variation

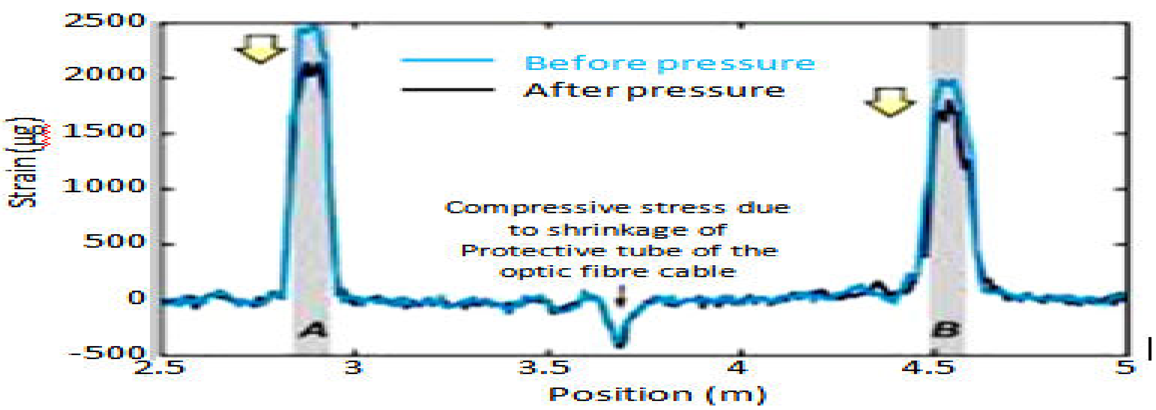

Fig 6: OTDR Graphical analysis of pressure effect on optic fibre

The cable was crushed between two plates while measuring optical power loss see Fig 6.

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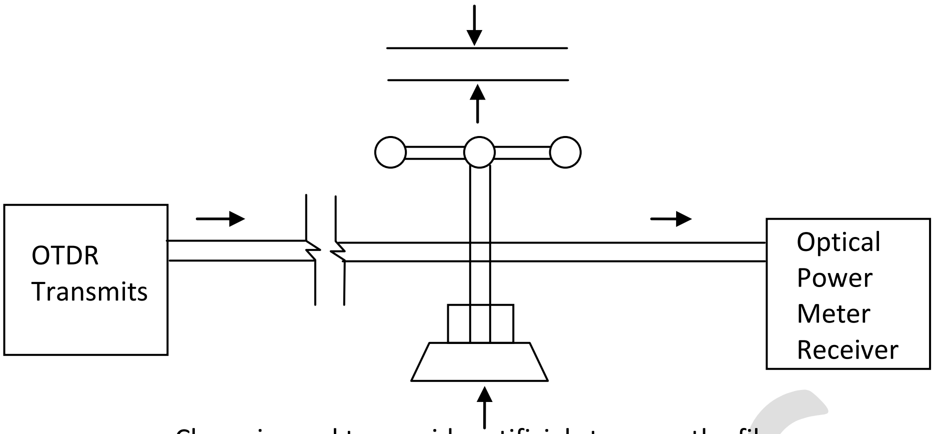

Fig 7: Destructive test on an optical fibre cable

Optical power meter was used when testing power loss attenuation. Severalweights where applied on the crushing apparatus and then the fibre tested to see the maximum weight at which no output would be received at the end point.

This was discovered to be at 3000N.

This confirmed that crush and impact pressure where also sources of chromaticdispersion i.e. the pulses at the affected locations experienced signal spreading such that the signals were indistinguishable at the receiver end.

Apart from the bending loss experiment using varying loads, the researcher also carried out a near destructive testing of the fibre using single mode optical pigtails.

The essence was to obtain a near sharply bent fibre and the attenuation level that could cause them. In this respect, the objective is to obtain the effect of attenuation (over the range of 3.0db – 34.0 db) on an optical signal. Instruments used include viz:

- Wavetek MTs 5100 Optical Time Domain Reflectometer (used as an optical source).
- Siemens optical variable attenuator with d.c. power source.
- Siemens optical power meter with d.c. power source.
- signal mode optical pigtails.

The investigation involved:

- The optical time domain reflectometer (OTDR) configured to work as an optical source.
- Using a single mode (SM) optical pigtail, and linking it up with an optical variable attenuator (OTDR output to attenuator input)
- Linking the attenuator output to the power meter input using another optical pigtail.
- Transmitting at 0.48mw of optical energy in the 1555nm wavelength with the attenuator and power meter on.
- Adjusting the value of the attenuator downwards until the received level on the display in the optical meter started changing.

IV. CRUSH/IMPACT TEST RESULTS

Sequel to the test of loading and results obtained from Fig 7 the graphical effect of distance and strain, clearly shows the effect of pressure on optic fibre.Similarly the setup confirms the assumptions.

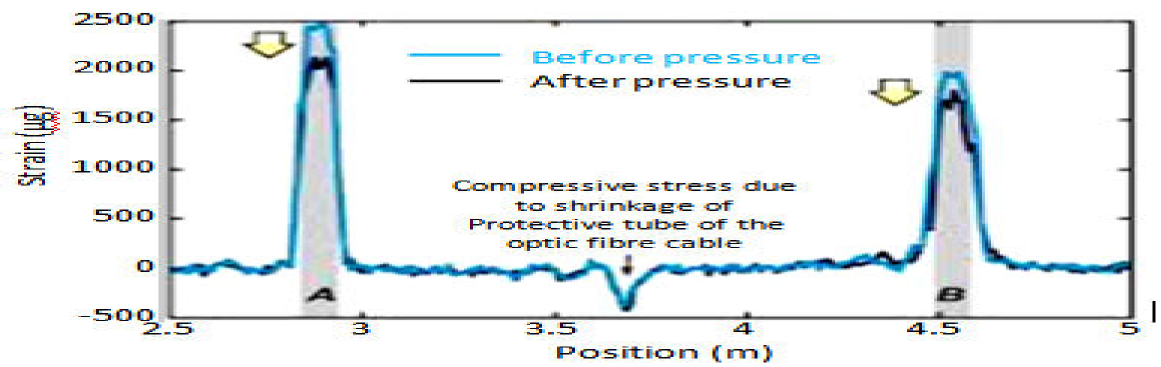

Fig 8: OTDR Graphical analysis of pressure effect on optic fibre

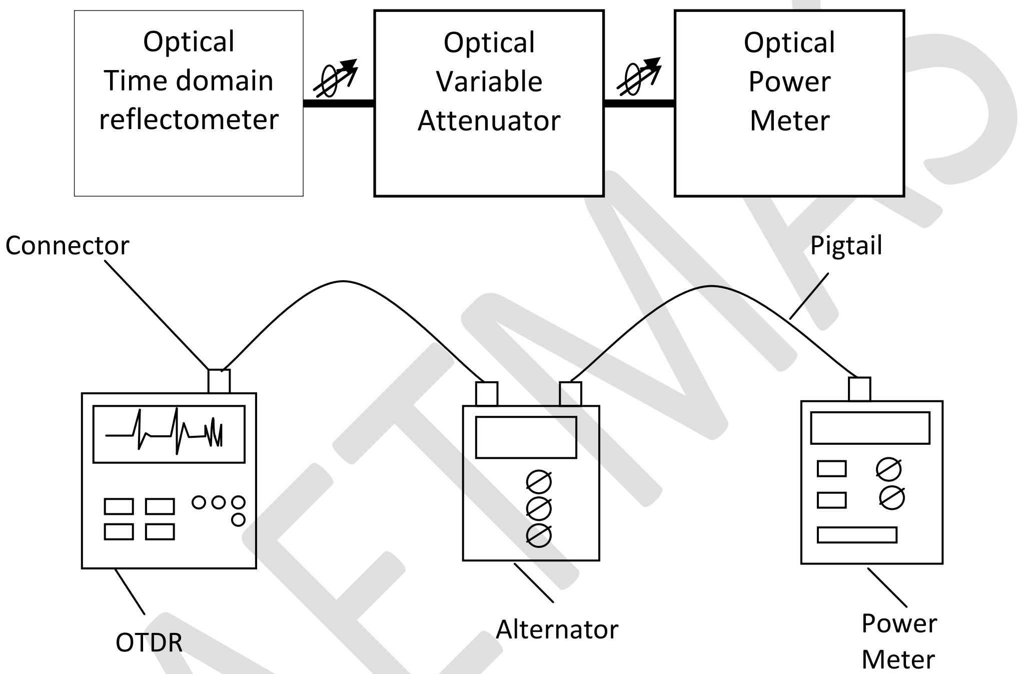

Fig 9: The details for the measurement of the near destructive test

This new measurement confirms that pressure has very great effect on the propagation and spreading of pulse alone the fibre due to implementation WDM. This was discovered from crushing test carried out in Table 1. Essentially, the crushing test on fibre death zone included:

A. Fibre – 24 core
B. Length – 60 kg/km
C. Max. stressed diameter - 110mm
D. Crushing resistance (pressure) - 2000N

Table 1: Crushing Test – Maximum stressed guage and Load

Cable Weight/length kg/km	**Maximum Bend Diameter (mm)**	**Maximum Load (N)**	**Crushing Load (N)**
60	110	1200	2000
85	130	1800	2000
100	148	2,200	2500
130	160	2700	2800
205	200	4,000	2000

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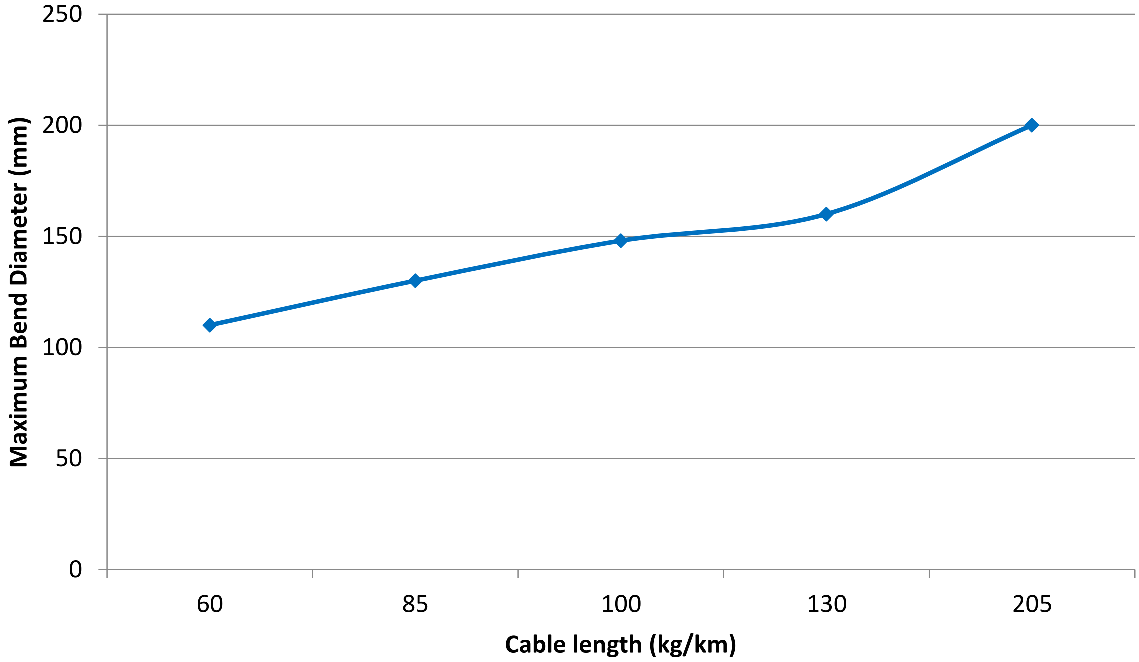

Fig 10 : Cable length vs maximum bend diameter

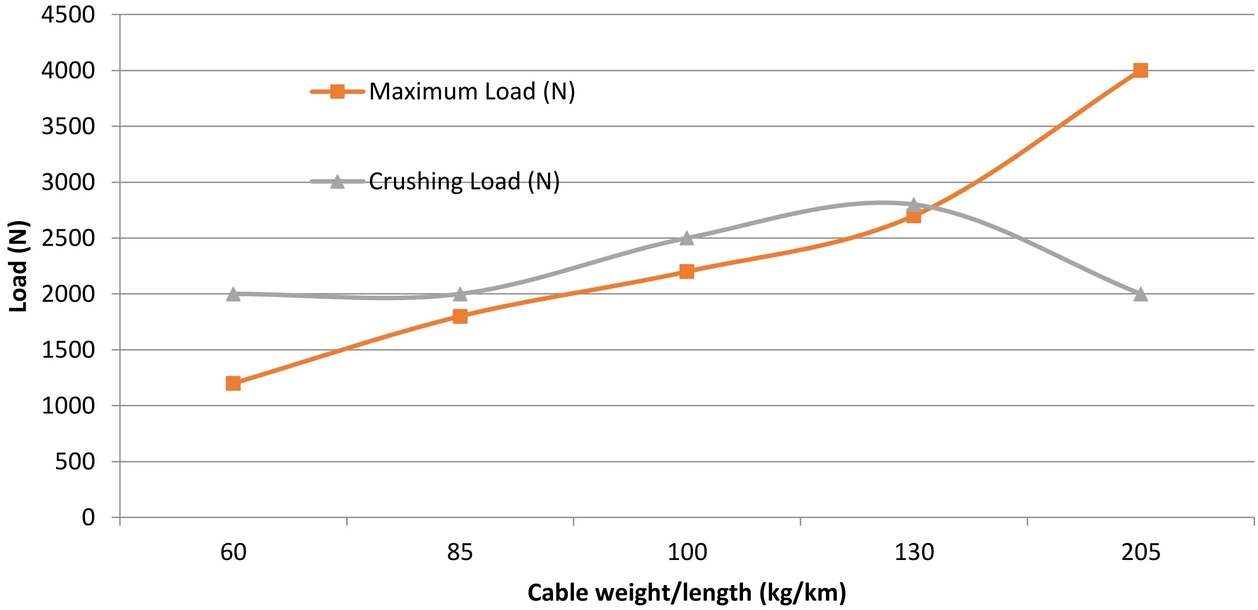

Fig 11: Cable weigth/Lenghtvs Maximum & Crushing Load for Abuja Nsa-Aso Drive –Nsa Zone4 route

The purpose of this experiment is to monitor the effect of pressure on the optic fibre cable irrespective of cable diameter and natural aperture see Table 2. It is established that as the pressure increases, dispersion value increases linearly as shown in Figs 12 and 13. Dispersion and Attenuation vs Crushing Load.

Table 2: Crushing Test – Attenuation and Dispersion

Crushing loading (N)	Attenuation dB	Dispersion dB/Km
500	0.20	16.65
1000	0.20	16.68
1500	0.21	16.72
2000	0.21	16.92
2,500	0.3	20.21
3,000	0.8	22.74

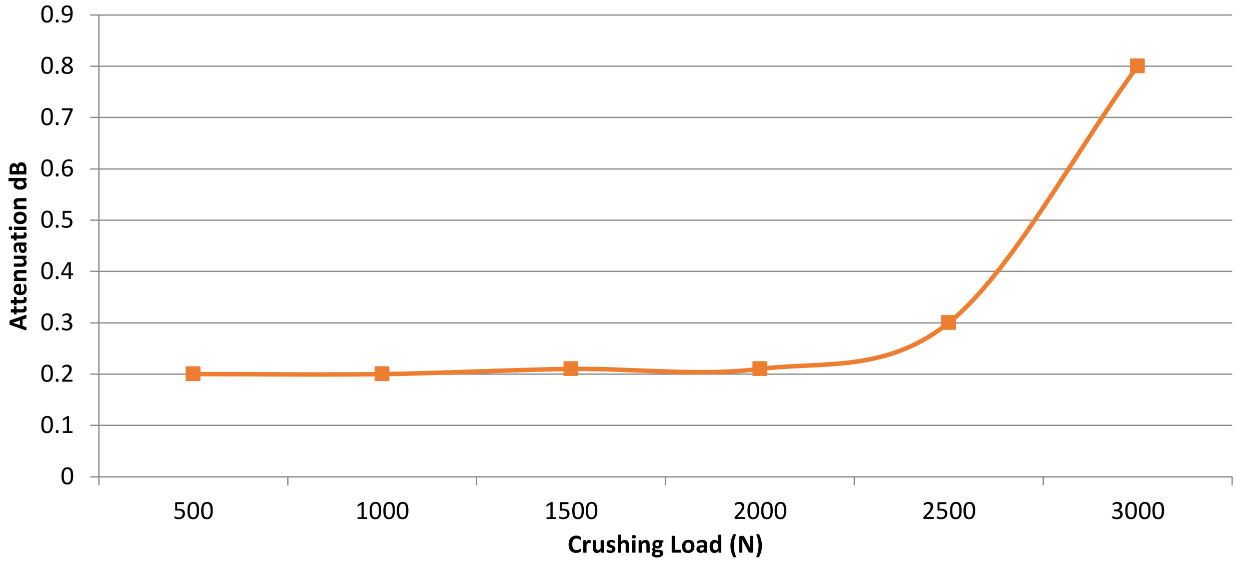

Fig 12: Crushing Load Vs Attenuation for Abuja NsaAso Drive - Nsa Zone4 route

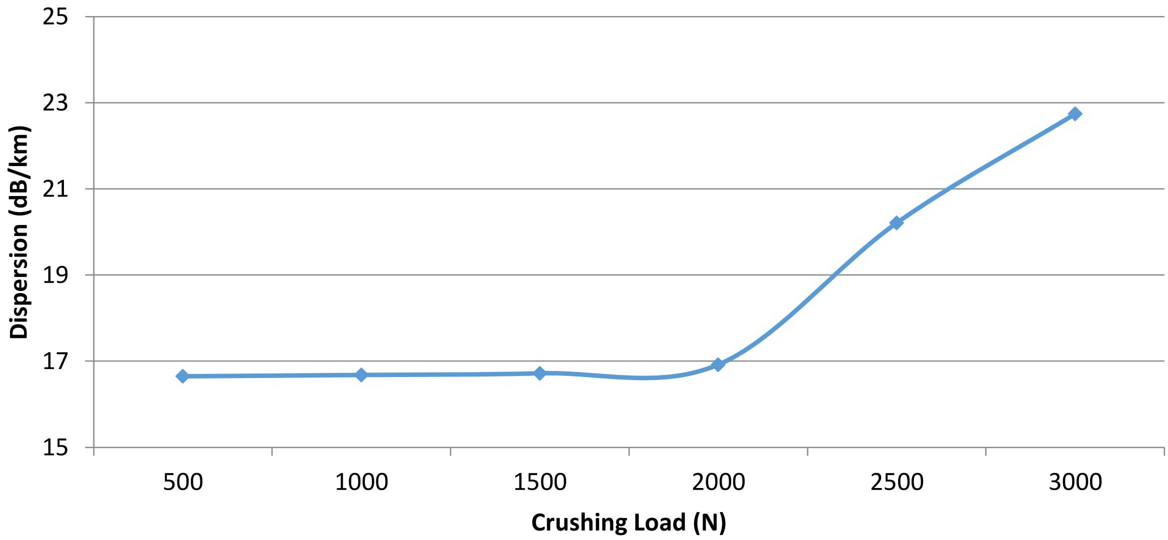

Fig 13: Crushing Load Vs Dispersion.

From the analysis increase in crushing load is directly related to rise in dispersion as shown Fig 12 and

13.The next step was calling on the Federal
Ministry of Works to visit construction sites and observe the operation and construction guide lines.

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2.0 Power Budget Tests

These tests were used to calculate losses along the trunk route irrespective of the topology of the route. This research work treats these trunks as bus topologies, since these were major trunk routes that carry heavy traffic. Power budget deals with power injected into the system from the input to output power together with the losses incurred from the splices, connectors, couplers etc.

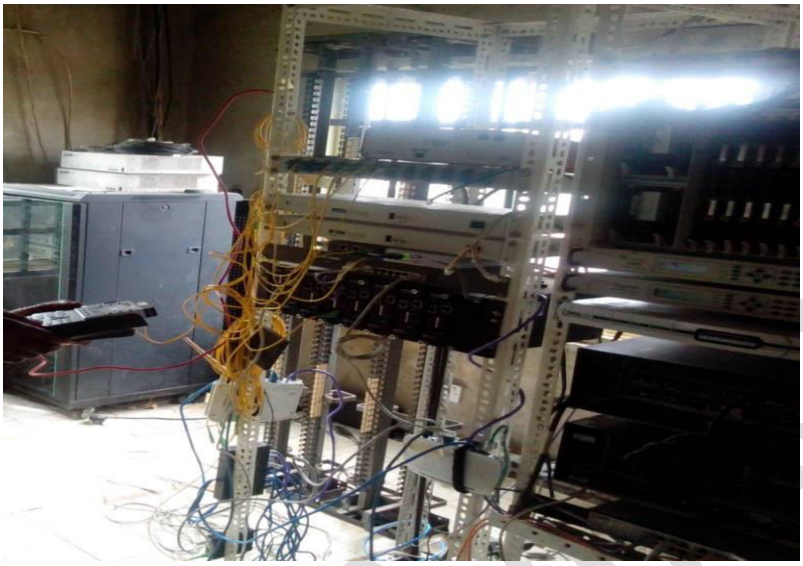

Fig 14: Power budget test

Optical Power Level Measurement (Power Budget) Data

The optical power level as the signal transmitted over a given distance was measured see Table 3. To measure the optical loss, a known level of light is transmitted from the light source directly to a power meter without the system or any of its components in place. The power meter then references out this known level which becomes the reference level. Once this reference is known, the light source is then connected to the system under test and reference levels correspond to the loss of the link. In the present work the OTDR was used. As an integrating system it handled all the process (received, analyzed and sent out the result plotted) thus the reading of the power level as the signal transmitted was recorded by the OTDR automatically.

Table 3: Power Level as Signal is transmittedthrough the Fibre

Fiber Pair in zp(km)	T= 0.1	T= 0.2	T= 0.3	T= 0.4	T= 0.5	T= 0.6	T= 0.7	T= 0.8	T= 0.9
1.0	-92.30	-81.10	-68.10	-61.40	-50.90	-39.80	-31.40	-22.30	-11.20
2.0	-44.80	-43.10	-38.10	-29.10	-26.10	-21.10	-16.30	-10.90	-5.30
3.0	-31.20	-27.20	-22.20	-14.40	-17.30	-14.10	-11.10	-7.30	-3.50
4.0	-23.40	-21.10	-18.10	-11.90	-12.90	-11.20	-8.20	-5.90	-2.70
5.0	-19.50	-17.10	-14.30	-11.10	-11.10	-9.10	-6.80	-5.10	-2.10
6.0	-14.60	-14.10	-12.60	-9.20	-9.20	-6.90	-6.10	-3.60	-1.70
7.0	-13.80	-12.30	-11.10	-7.90	-8.10	-6.10	-4.90	-3.10	-1.30
8.0	-12.40	-10.10	-8.90	-7.10	-7.20	-5.30	-3.60	-2.40	-1.20
9.0	-11.40	-8.30	-7.40	-6.91	-6.80	-4.70	-3.30	-2.20	-1.10
1.0	-8.60	-8.10	-7.10	-6.30	-5.20	-4.20	-2.90	-1.90	-1.10

Zp= Fiber per Distance. T locations of testing point

V. CONCLUSION

From this study it is very clear that the heavy weights on fibre optics cable brings about bending losses on the cable,this creates room for reduction in bandwidth. Poor bit error rate (BER) and finally lunches into chromatic dispersion.Chromatic dispersion which is the broadening of signals at the output of the system is the mother of dispersion losses in fibre optics.To avoid pneumatic effect on fibreoptics the installation must be properly carried out. Direct burial must be avoided as areas where heavy trunk ply,ducting of cable must be the practice trenches for cable laying must be atleast three meters deep with a casing of either concrete or metal pipe to minimise these pneumatic pressures.As this will ensure efficient and effective use of optical fibre in communication systems.

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